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APPLICATION FOR UNITED STATES LETTERS PATENT

Title:

APPARATUS AND METHOD FOR REDUCING OPERATING STRESS IN A TURBINE BLADE AND THE LIKE

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The invention was made by or under contract with the Navy of the United States Government under contract number N00019-02-C-3003.

APPARATUS AND METHOD FOR REDUCING OPERATING STRESS IN A TURBINE BLADE AND THE LIKE

Governments Rights in the Invention

[0001] The invention was made by or under contract with the Navy of the United States Government under contract number N00019-02-C-3003.

Field of the Disclosure

[0002] The present disclosure generally relates to a method and apparatus for designing and manufacturing a cast part to minimize mechanical operating stress, and more particularly to minimizing operating stress in a turbine blade.

Background of the Disclosure

[0003] Component casting is typically used when large quantities of identical products are being produced or when design specifications require intricate internal geometry that machining apparatus such as mills, drill presses, and/or lathes cannot access. Highly stressed components such as turbine blades in gas turbine engines require casting techniques that minimize localized stress caused by internal geometric features. Turbine blades, and the like, have internal hollow portions to reduce the weight of the blade and provide passages for cooling air flow. Cooling air flow is required because the external operating temperatures of the exhaust gas flow exceed the melting temperature of metal alloys used in gas turbine engines.

[0004] Turbine blades with cooling passages and stress reducing methods are known in the prior art. For example, U.S. Patent No. 6,533,547 issued to Anding et al. on March 18, 2003, discloses a turbine blade having internal space through which coolant fluid is guided and in which stiffening ribs are formed to reinforce and support the external walls.

Coolant screens that reduce the cooling of the stiffening ribs are arranged in front of the stiffening ribs in order to reduce thermal stresses.

[0005] Cores for casting turbine blades are typically made of ceramic composite or the like. Casting cores have solid portions separated by hollow portions. The solid portions of the core form hollow portions in the final product, likewise the hollow portions of the core are where the metal portions are formed in the final product. The solid portions of the casting core will fracture if not supported adequately during the manufacturing process. To prevent core fracture, support elements or "tie features" are designed in the core to extend between adjacent solid portions. These support elements necessarily produce through apertures in the internal walls of the turbine blade. It would be desirable to design these elements to provide adequate mechanical support to the core, while at the same time minimizing operating stress that the resulting through apertures cause in the turbine blade .

Summary of the Disclosure

[0006] In accordance with one aspect of the present disclosure, a core for casting a metal part is provided. The core includes a body having solid portions spaced apart by hollow portions. The body also includes at least one support element extending between adjacent solid portions. The support element has a shape optimized to prevent the core from fracturing during the casting process and designed to minimize operating mechanical stress in the metal part formed by the support element.

[0007] In accordance with another aspect of the present disclosure, a method for designing a casting core is provided. The method defines a cross section for a support element by defining a first radius with a center point and a circumferential arc. Next, a second radius is defined with a center point and a circumferential arc positioned a first distance from

the first center point. A third radius is defined by a center point and a circumferential arc positioned a second distance from the center point of the second radius. The design method further defines a fourth radius having a center point and circumferential arc positioned tangent to the circumferential arcs of the first, second, and third radii. A fifth radius having circumferential arcs positioned tangent to the circumference of the first, second and third radii and opposite of the fourth arc is also defined. The method produces a core support feature that adequately supports the core during the casting process and minimizes stress in the cast part.

[0008] In accordance with another aspect of the disclosure, a method for manufacturing a casting core is provided. The method includes providing ceramic slurry for delivery into a core die and forming a green core. The green core includes solid portions spaced apart by corresponding hollow portions. At least one support element is formed between adjacent solid portions of the core. The casting core is removed from the die and allowed to dry and then heated to a predetermined temperature to increase the material strength. The support elements are formed by defining a first radius, and a second radius a first distance from the first radius. A third radius is positioned a second distance from the second radius. A fourth radius having a circumference positioned tangent to the circumference of the first, second and third radii forms one side of a cross-section. A fifth radius having a circumference positioned tangent to the circumference of the first, second and third radii forms the opposite side of the cross section. The first and second radii can be substantially equal in length as can the fourth and fifth radii. The first and second distances can also be substantially equal in length.

[0009] In accordance with another aspect of the disclosure, a method for forming a cast part is disclosed. The method includes forming a ceramic core with at least one support element extending between adjacent solid portions of the core. The support

element is formed with a cross-section designed to minimize operating stress in the cast part. A wax die is formed to define external geometry of the cast part. Wax is then injected into the wax die to form a wax pattern of the cast part. The ceramic core is placed into the wax die to produce the internal geometry of the cast part. Ceramic slurry is introduced into the wax pattern to form a mold shell. The mold is dried and the wax is melts when the mold is heated to a predetermined temperature. The mold is then cooled to a predetermined temperature and preheated to at least the melting temperature of the casting material. Molten casting material is poured into the mold, and then cooled in a controlled environment. The casting mold shell is removed from the cast part. The casting is then leached with a chemical solution to remove the ceramic core from the cast part. The cast part is inspected with N-ray to check that the core has been removed. The surface of the cast is etched and a laue'ding procedure is utilized to inspect the grain structure of the cast part. The surface of the cast part is inspected with fluorescent penetrate to determine whether surface cracking exists. The internal features of the cast part are inspected with X-ray. The cast part is machined to meet the specification and is then inspected for dimensional quality. Finally, the cast part is flow tested to check the internal passages.

[0010] In accordance with a still further aspect of the disclosure, a turbine blade can be manufactured according to the method described above to produce an air foil having solid portions with at least one through aperture formed therein by the casting core. The through aperture has a shaped optimized to minimize operating mechanical stress in a localized area around the aperture. The cast metal part is formed from a casting core that includes a body having solid portions spaced apart by hollow portions and at least one support element extending between adjacent solid portions that forms a through aperture in the cast metal part.

[0011] These and other aspects and features of the disclosure will become more apparent upon reading the following detailed description when taken in conjunction with the accompanying drawings.

Brief Description of the Drawings

[0012] FIG. 1 is a cross-section of a typical gas turbine engine;

[0013] FIG. 2 is a front view of a turbine rotor;

[0014] FIG. 3A is a side view of a casting core for a turbine blade;

[0015] FIG. 3B is an enlarged view of a portion of FIG. 3A showing a support element;

[0016] FIG. 4 is a cross-sectional view of the support element of FIG. 3A;

[0017] FIG. 5 is a perspective view rotor blade partially cut-away to show the casting core of Fig. 3A;

[0018] FIG. 6 is a portion of the cast turbine blade after the core has been removed to show internal passages of the turbine blade;

[0019] FIG. 7A is a portion of the turbine blade showing an irregular aperture formed from an undefined casting support element;

[0020] FIG. 7B is a portion of the turbine blade showing an circular aperture formed from a casting support element having a circular cross section; and

[0021] FIG. 7C is a portion of the turbine blade showing an aperture formed from a casting support element having a cross section defined by the present disclosure.

[0022] While the disclosure is susceptible to various modifications and alternative constructions, certain illustrative embodiments thereof have been shown in the

drawings and will be described below in detail. It should be understood, however, that there is no intention to limit the present disclosure to the specific forms disclosed, but on contrary, the intention is to cover all modifications, alternative constructions, and equivalents falling within the spirit and scope of the disclosure as defined by the appended claims.

Detailed Description Of The Disclosure

[0023] The present disclosure provides for an apparatus design and method for minimizing operating stress on parts manufactured by a casting process. In one embodiment of the present disclosure, the cast part is a turbine blade for a gas turbine engine, however, the cast part can be any of the type having complex internal geometry and subjected to high stresses during operation. The design and method can be used for both moving and static geometry.

[0024] Referring now to FIG. 1, a cross-section of a typical gas turbine engine 10 is shown therein. The gas turbine engine 10 includes an outer case 12 to hold the internal turbo-machinery components and to attach the engine 10 to an aerospace vehicle (not shown). The gas turbine engine 10 includes a rotor 14 that includes a shaft 15 extending from the front of the engine to the rear of the engine. The casing 12 forms an inlet 18 in which air enters past a nosecone 16 and into the engine 10. The rotor can include an axial compressor 20 having at least one stage. The compressor 20 is operable for compressing the air and delivering the compressed air to a combustor 22. The combustor 22 receives the compressed air and a fuel to burn therein. The combustion gas mixture expands at high velocity through a turbine 24 having at least one stage. A turbine stator 25 can be positioned between each turbine rotor stage to remove unsteady vortices and unstructured flow patterns to provide a predetermined velocity profile of the gas flow prior to entering the next stage of the turbine

24. A nozzle 26 accelerates the flow exiting the turbine 24 to increase the velocity mass flow which generates the thrust to propel the aerospace vehicle.

[0025] Referring now to FIG. 2, a view of the turbine rotor is shown therein. The turbine rotor 24 has a plurality of blades 30 connected to a turbine disk 31. The turbine rotor 24 spins a high rotational speed. This high rotational speed produces a large centripetal force which creates large stresses inside the turbine blade. Additional stress is imparted on the turbine blades 30 when impacted by the high velocity air. Further stress can be generated due to thermal gradients formed during operation of the engine 10. Engine components are designed to minimize weight to achieve specified performance, but must maintain durability and reliability for a given design lifespan. To meet these performance goals and design life requirements, stress producing features such as internal holes and fillets must be designed to minimize local stress around those areas.

[0026] Referring now to FIG. 3A, a casting core 32 for a turbine blade 30 is shown therein. The casting core 32 can be made of a ceramic or other composite materials designed to withstand the high temperatures and pressures generated during the casting process. The casting core produces the mirror image of itself in the final turbine blade 30. The casting core 32 has solid portions 34 spaced apart by hollow portions 36. The solid portions 34 form the internal cavities of the turbine blade 30 and the hollow portions 36 form the metal portions of the turbine blade 30. The turbine core 32 requires at least one support element 38 to extend between adjacent solid portions 34 through a hollow portion 36 to prevent the core from fracturing during the casting process. FIG. 3B shows an enlarged portion of the core 32 having a support element 38. The support element 38 has a cross-sectional shape optimized to prevent the core from fracturing during the casting process and to minimize operating mechanical stress in the area of the metal part formed by the support element 38.

[0027] A cross-section 40 of the support element 38 is shown in FIG. 4. The cross-section is designed with generic curves defined below by several radii and corresponding arcs. The cross-section 40 can be scaled to a desired size for a given core 32. The cross section defines a shape that minimizes stress in the cast part. The cross-section 40 includes a first radius R1, a second radius R2, and a third radius R3 each defined by a center point 42, 44, and 46 respectively. The first radius R1 defines a circumferential arc 48, the second radius R2 defines a circumferential arc 50, and the third radius R3 defines a circumferential arc 52. The center point 42 of the first radius R1 and the center point 44 of the second radius R2 are separated by a first distance D1. The center point 44 of the radius R2 is separated a distance D2 from the center point 46 of the third radius R3. A fourth radius R4 having a center point 54 is positioned such that a circumferential arcs 56 defined by the radius R4 is positioned to be simultaneously tangent to the circumferential arcs 48, 50, 52 of the first, second and third radii R1, R2, R3 respectively. A fifth radius R5 having a center point 58 defines a circumferential arc 60 that is positioned opposite of the arc 56 of the fourth radius R4. The circumferential arc 60 of the fifth radius R5 is positioned so as to be simultaneously tangent to the first, second and third circumferential arcs 48, 50, 52 of the first, second and third radii R1, R2, R3 respectively. The cross-section 40 is bounded by the arcs 56, 60 of the fourth and fifth radii on the sides thereof and by the intersection of the arcs 56, 60 of the fourth and fifth radii at each end thereof.

[0028] According to one embodiment, the first and third radii R1, R3 can be substantially equal in length and the fourth and fifth radii R4, R5 can also be substantially equal in length. Also, the first distance D1 can be substantially equal in length to the second distance D2. Each of the circumferential arcs 48, 50, 52, 56, and 60 can be defined by a higher order curve that approximates a circular arc formed by a radius. For example, the

higher order curve could be a spine curve or a B-spine curve, but is not necessarily limited to those particular definitions.

[0029] In order to manufacture a casting core 32, the following method may be employed. First a ceramic slurry is injected into a core die (not shown) to form a green core. The core die forms solid portions 34 spaced apart by corresponding hollow portions 36, and at least one support element 38 extending between adjacent solid core portions. After solidifying, the core 32 is removed from the die and allowed to completely dry. After drying, the core 32 is then heated at a predetermined temperature to increase material strength. The outer surface of the core 32 is process treated to increase strength prior to machining the core to final dimensional specifications. The cross-section 40 of the at least one support element 38 may be formed according to the method described above.

[0030] A method for forming a cast part with a ceramic core having at least one support element 38 element having a cross-section 40 design to minimize operational stress in the cast part as well as provide stiffening support for the core 32 during the casting process is also contemplated by the present disclosure. The method includes forming a wax die (not shown) to define the external geometry of the cast part. The casting core 32 is inserted into the wax die. Wax is then injected into the wax die to form a wax pattern of the external shape of the cast part. Ceramic slurry is then introduced into the wax pattern to form a mold shell. The mold is dried and the wax is removed by heating the mold to a predetermined temperature to melt the wax. This heating process also increases the strength of the ceramic mold. The ceramic mold is cooled to a predetermined temperature and then preheated to the approximate melting temperature of the casting material. The molten casting material is then poured into the mold. The mold is cooled in a controlled environment. The casting mold shell is removed from the cast part and the casting core 32 is leached with acid of a type known in the art to remove the ceramic core from the cast part. The cast part is then

inspected with N-ray to verify that all of the core material has been removed. The surface of the cast part is etched and a laue'ding procedure is performed to inspect the grain structure of the cast part and ensure structural integrity. The surface of the cast part is then inspected with a fluorescent penetrate to determine whether any flaws such as cracks have formed. The internal features of the cast part are inspected with X-ray. The cast part is then finish machined and inspected to final external dimensions. A flow test is performed to determine whether the internal passages were formed correctly.

[0031] Referring now to FIG. 5, a turbine blade 30 is shown partially cut-away with the ceramic core 32 shown internal thereto. FIG. 6 shows an internal structure 70 of the turbine blade 30 after the ceramic core 32 has been removed. More specifically, a plurality of passages 72 is formed in the turbine blade 30 to provide channels for cooling air flow to circulate therein and keep the blade 30 below the design temperature limit. Each cooling passage 72 includes a pair of side walls 74 bounded by the external surfaces 76, 78 of the blade 30. Each core support element 38 forms a through aperture 80 in the side walls 74 of the air passages 72. These apertures 80 cause high stress in localized areas surrounding the aperture 80. As such, it is desirable that the shape of the apertures 80 are designed to minimize the localized stress in the blade 30 according to the method described above.

[0032] FIG. 7A shows a portion of a turbine blade 30 having an irregular aperture 80a formed from an undefined casting support element 38. FIG. 7B shows a portion of a turbine blade 30 having a circular aperture 80b formed from a casting support element having a circular cross section. FIG. 7C shows a portion of a turbine blade 30 with an aperture formed from a casting support element having a cross section defined by the present disclosure. The turbine blade 30 of FIG. 7C was analyzed using Finite Element Analysis (FEA), a computational design tool that allows design engineers to model a particular part and simulate operational loads such as inertial forces, thermal gradients, pressure forces, and

the like. The FEA model analytically breaks the solid part into a series of discreet geometric elements such as "bricks" or "tetrahedrons", etc, and calculates the stress at each element induced by the simulated operational loads. The design study performed lead to the discovery that stress levels associated with the aperture 80c having the newly designed geometry of FIG. 7C were approximately 50% of the stress levels associated with the apertures 80a, 80b shown in FIGS. 7A and 7B.

[0033] While certain representative embodiments and details have been shown for purposes of illustrating the disclosure, it will be apparent to those skilled in the art that various changes in the methods and apparatus disclosed herein may be made without departing from the scope of the disclosure, which is defined in the appended claims.